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Effect of Socioeconomic Status (SES) Disparity on Neural Development in Female African-American Infants at 1 Month

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Abstract

There is increasing interest in both the cumulative and long term impact of early life adversity on brain structure and function, especially as the brain is both highly vulnerable and highly adaptive during childhood. Relationships between SES and neural development have been shown in children older than age two years. Less is known regarding the impact of SES on neural development in children before age two. This paper examines the effect of SES, indexed by income-to-needs (ITN) and maternal education, on cortical, deep gray, and white matter volumes in term, healthy, appropriate for gestational age, African American, female infants. At 44-46 post-conception weeks, unsedated infants underwent MRI (3.0T Siemens Verio scanner, 32-channel head coil). Images were segmented based on a locally-constructed template. Utilizing hierarchical linear regression, overall and component (maternal education and ITN) SES effects on MRI volumes were examined. In this cohort of healthy African American infants of varying SES, lower SES was associated with smaller cortical gray and deep gray matter volumes. These SES effects on neural outcome at such a young age build on similar studies of older children, suggesting that the biological embedding of adversity may occur very early in development.

Keywords

infant, MRI, socioeconomic status, development, neural, poverty

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UNDER REVIEW
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Effect of Socioeconomic Status (SES) Disparity on Infant Neural Development at Age 1 Month

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Abbreviations:
EDC - Estimated Date of Confinement; BW - Birth Weight; HC - Head Circumference; ITN - Income to Needs; MRI- Magnetic Resonance Imaging; SES - Socioeconomic Status; Nifti - Neuroimaging Informatics Technology Initiative;

Keywords:
infant, MRI, socioeconomic status, development, neural, poverty

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Research Highlights:

- Report utilized a birth cohort of term, healthy, appropriate for gestational age, African American, female infants.
- Examined relation between SES and cortical volume in infants at age 4-6 weeks.
- Lower SES was associated with smaller cortical gray and deep gray matter volumes.
- Findings push back the age at which SES effects can be observed from early childhood to early infancy.

Abstract

There is increasing interest in both the cumulative and long term impact of early life adversity on brain structure and function, especially as the brain is both highly vulnerable and highly adaptive during childhood. Relationships between SES and neural development have been shown in children older than age two years. Less is known regarding the impact of SES on neural development in children before age two. This paper examines the effect of SES, indexed by income-to-needs (ITN) and maternal education, on cortical, deep gray, and white matter volumes in term, healthy, appropriate for gestational age, African American, female infants. At 44-46 post-conception weeks, unsedated infants underwent MRI (3.0T Siemens Verio scanner, 32-channel head coil). Images were segmented based on a locally-constructed template. Utilizing hierarchical linear regression, overall and component (maternal education and ITN) SES effects on MRI volumes were examined. In this cohort of healthy African American infants of varying SES, lower SES was associated with smaller cortical gray and deep gray matter volumes. These SES effects on neural outcome at such a young age build on similar studies of older children, suggesting that the biological embedding of adversity may occur very early in development.

Childhood socioeconomic status (SES) is associated with lifelong mental health and intellectual attainment, presumably through its effects on neural development. On average, poor children differ from their higher SES counterparts by performing lower on IQ tests (Nisbett et al., 2012), achieving less success in school (Sirin, 2005), and suffering at a higher rate from mental disorders such as ADHD, anxiety and depression (Goodman, 1999; Kessler et al., 2005). On behavioral testing designed to identify the neurocognitive profile of poverty, that is, the pattern of relatively spared and impaired abilities associated with particular brain regions, the largest disparities are found on tests of executive function, memory and language (Farah et al., 2006; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005).

Recent brain imaging studies have sought more direct anatomical evidence of SES effects on neural development based on measures of gray and white matter associated with the abilities just discussed (Brito & Noble, 2014). With one exception (Hanson, et al., 2013), these studies have focused on school-aged children and adolescents. Analyses of differences in gray matter volume as a function of SES found positive relations in some studies (Hanson et al., 2013; Luby et al., 2013) and no relation in others (Almli, Rivkin, & McKinstry, 2007; Brain Development Cooperative Group, 2012). Similarly, findings regarding SES effects on white matter vary, with some reporting effects (Luby, et al., 2013) and others reporting no effects (Brain Development Cooperative Group, 2012; Hanson, et al., 2013). Voxel based morphometry(VBM) and region of interest (ROI) analyses have supported the existence of regional gray matter correlates of SES in children. Among the most reliably observed areas correlating with SES are prefrontal cortex, the hippocampus and amygdala. While two analyses of the

large National Institute of Health (NIH) MRI Study of Normal Brain Development for children aged 4-18 years found no SES effects on specific lobar volumes, the same sample showed thinner cortex within certain prefrontal regions (Lawson, Duda, Avants, Wu, & Farah, 2013; Noble, Houston, Kan, & Sowell, 2012). The NIH MRI Study of Normal Brain Development's sample of younger children, mean age 13 months, showed higher SES was associated with more frontal gray matter (Hanson, et al., 2013). Raizada et al. (2008) found a marginally significant effect of SES on gray matter volume in the left inferior frontal gyrus, with higher SES associated with greater volume (Raizada, Richards, Meltzoff, & Kuhl, 2008). Although Noble, Houston and Sowell (2012) did not find a main effect of SES on the left inferior frontal gyrus in the 5 – 17 year-olds they studied, they did observe an interaction between age and SES in this area, with progressively larger volumes for high SES children as their age increased. ROI analyses have also documented SES differences in hippocampal volume (Hanson et al., 2011; Hanson et al., 2014; Luby et al, 2013; Noble et al., 2012) and amygdala volume (Hanson et al., 2014; Luby et al., 2013; Noble et al., 2012 but not Hanson et al., 2011), regions also found to correlate with SES in the whole brain VBM of Jednorog et al., 2012.

Although much more research is needed to firmly establish the existence of structural brain correlates of childhood SES and to identify specific patterns of areas affected, the available research suggests the provisional conclusion that SES does affect structural brain development in childhood. In contrast to the question of whether SES has structural brain correlates in childhood, which has a provisional answer, two related questions remain entirely open. The present study is a first attempt to address these two questions.

The first question addressed here concerns the age at which the effects of SES are manifest in child brain structure. The developmental origins of these morphological differences are currently not known. The youngest sample analyzed for SES effects on brain structure is that of Hanson and colleagues. Visual inspection of the growth curves derived by Hanson and colleagues for low, middle and high SES children (n=77) show overlap at 5 months of age and appear to diverge only later, with low SES separating from middle and high SES at close to one year. However, very few subjects in this sample were 5 months old; the mean age of subjects at the first of the longitudinally collected scans was 13.5 months. In addition, such curves are fit to data points from multiple ages, so that the precise position of curves at 5 months depends on later measurements. Presumably for these reasons, the authors did not state any conclusions about the age at which effects of SES emerge. There are no other findings in the literature to inform us concerning SES effects on brain structure in toddlerhood or before.

The timing of the emergence of effects can be informative as to their causes. As Hanson and colleagues point out, differences that emerge and widen in postnatal life are most simply explained by postnatal causes. Conversely, differences present at birth may result from prenatal factors, known to vary with SES, or from genetic factors, or from their interaction (Ivanovic et al., 2004). Although the present study did not obtain brain images immediately after birth, subjects were 5 weeks old on average, minimizing the opportunity for postnatal influence.

The second question addressed here concerns the effect of poverty per se as opposed to SES more generally. In contrast to SES, which refers to the whole range of economic, educational and occupational status in our society, poverty refers to the very

lowest levels of financial status and accompanying social factors including low educational attainment. For both policy and research purposes, poverty is typically gauged by the ratio of income to needs (ITN), with the US "poverty line" defined as an ITN of 1. No previous study of brain structure has compared children who were poor, by this criterion, with non-poor children; indeed the NIH MRI Study of Normal Brain Development samples used by the Brain Development Cooperative Group (2012), Hanson et al. (2011, 2013), Lange et al. (2010) and Lawson et al. (2013) are predominantly middle class. Furthermore, stringent exclusionary criteria for the Study of Normal Brain Development sample eliminated children disproportionately from lower levels of SES (Waber et al., 2007). Samples from other studies cited above have wider ranges of SES, but none contain primarily poor and near-poor children. With 22% of American children classified as poor according to the Federal standards, this comparison is socially and scientifically relevant, and hence the sample studied for this report is approximately half poor and half near-poor.

On the basis of the research just reviewed, we hypothesized an early association of SES and cortical gray matter volume in infants at age 4-6 weeks. In addition we undertook analyses of the association between SES and both deep gray matter and white matter volumes.

Methods

Participant recruitment and inclusion criteria

Mothers and their infants were recruited at time of delivery from a single hospital. Mothers were eligible for inclusion if they were between 18 and 45 years of age and

declared that both parents were American-born African American. Potential participants were excluded if they were foreign born, non-English speaking, had significant psychiatric diagnoses, were enrolled in an alcohol or drug rehabilitation program, or had significant medical or obstetrical conditions as defined by the obstetrical service. Infants eligible for inclusion were female singletons born at 38-42 weeks gestational age, with birth weights appropriate for gestational age, and 5-minute Apgar scores ≥8. Infants were excluded if they were diagnosed with any condition associated with developmental delay, required hospitalization of more than 3 days, failed a hearing screen, or were not discharged to their biologic mother. Target enrollment was 30 low SES infants and mothers and 30 higher SES infants and mothers. Upon enrollment all participants signed informed consent for this project that was approved by Institutional Review Board.

Income to Needs: SES was indexed by income-to-needs (ITN) and maternal education. Low SES (poor group) was defined as ITN at or below government poverty line plus no more than high school education. Higher SES (near- poor) had ITN above the poverty line plus at least a high school education. The ITN variable was based on the 2013 US government official poverty definition(U.S. Census Bureau, 2013) and was ascertained by maternal self-report of household income and composition. Mothers and infants were categorized into one of five ITN categories according to income and family size. For example, the poverty threshold for a family of two is $15,510 per year. Families making less than this amount are classified as below the poverty line (ITN = 1). A family of two making $62,040 per year is classified in the higher end of the range at 400% above the poverty line (ITN = 5). The remaining three ITN categories were distributed between the low and higher income range. The education variable was

ascertained from maternal self-report and ranged from some high school through graduate school. An SES Composite score was computed by rescaling ITN values to match the scale for values of maternal education and summing them, giving these two dimensions of SES equal weight. Because nearly two thirds of the infants in the current cohort were living in households that did not include their biological father, we used maternal education and not paternal education in the composite (Entwislea & Astone, 1994).

Image acquisition and processing

Infants underwent MRI scans at approximately 5 weeks post estimated date of confinement (EDC). No sedation was utilized. Appointments were scheduled for parent-reported infant nap times. Infants were fed, swaddled, and acclimated to the scanner room before placement in the scanner. High resolution T1 and T2-weighted and diffusion-weighted images were obtained utilizing a 3T Siemens Verio Scanner with a 32-channel head coil.

All subjects' images were converted into anonymous Neuroimaging Informatics Technology Initiative (Nifti) format before further processing. A population-specific template was built using data from 15 participants with high quality data. The final template was subsequently labeled with six spatial probability functions that defined the voxel-wise probability of distinct tissue/anatomical classes: cortical gray (which includes the hippocampus and amygdala), deep gray (includes thalamus and basal ganglia), white matter, brainstem, cerebellum, and cerebrospinal fluid. This method iteratively optimized both template shape and appearance in order to estimate an average brain that best represented the expected anatomy in the cohort (Tustison et al., 2014).

Diffeomorphic image registration (SyN algorithm, implemented in ANTs (Avants et al., 2014; Tustison, et al., 2014)) was used to map between template and subject space. This mapping was used to transfer the six template prior probability maps into the space of the individual's T2 MRI. T1 and diffusion-weighted MRI also were mapped into the space of the T2 via a low-dimensional registration. These three modalities were complemented by the Laplacian of the T2 image to form a rich feature space for basis of 6-tissue multivariate segmentation. The final segmentation procedure incorporated both T2 and T1 features with the probability maps via a Bayesian tissue segmentation algorithm, Atropos (Tustison, et al., 2014).

To verify quality, each segmentation was visually inspected, along with the original T1 and T2 data and data were reviewed for motion artifact. Given successful 6-tissue segmentation, cortex was further parcellated based on joint label fusion (Wang et al., 2013), the current state of the art multi-atlas labeling algorithm (The Medical Image Computing and Computer Assisted Intervention Society, 2013). Final regional labels were derived by performing joint label fusion based on the Makropoulous cohort (Makropoulos et al., 2014). The full processing pipeline is publicly available (Avants, et al., 2014). MRI data for this report include cortical gray, deep gray, and white matter volumes. Examiners were masked to SES status.

Analyses

Preliminary analyses included SES group comparisons of maternal and child characteristics using t-tests and Chi Square tests. Pearson correlations were utilized to test associations between demographic and MRI variables. Main analyses consisted of

hierarchical linear regressions using the SES composite as a continuous variable to examine SES effects on neural outcomes. Covariates were birth weight and post-conception age at scan (more predictive of developmental maturity than post-natal age for infants of this age (Hanson, et al., 2013; Martin, Fanaroff, & Walsh, 2011). A priori hypotheses were tested first, followed by exploratory testing. Analyses were performed using SPSS 22.0.

Results

Characteristics at time of enrollment and MRI are shown in Table 1 for the 44 participants (25 Low SES, 19 Higher SES). Low SES mothers were younger than Higher SES mothers and, per enrollment criteria, reported lower levels of education. Also per enrollment, the Low SES group were all of ITN category 1 and the Higher SES group all were of ITN category 2 or greater (74%= ITN 2, 26%≥ ITN 3). Infant birth characteristics and age at time of MRI were similar.

Of 46 scans completed, data from two subjects (both ITN of 1 and maternal education at the high school level) were not utilized due to motion and poor resolution. Correlations between cortical gray, deep gray, and white matter volumes and participant characteristics are shown in Table 2. Cortical gray matter volume was associated with the SES Composite, ITN, maternal education, gestational age, birth weight, head circumference and length, and post-conception age at MRI. Deep gray matter volume was associated with the SES Composite, maternal education, birth weight, head circumference and length and post-conception age at MRI. White matter volume was

significantly associated with only birth weight, head circumference and post-conception age at time of MRI.

To examine the relations between SES and volumes of cortical gray, deep gray, and white matter, three hierarchical linear regressions were conducted for each outcome, controlling for post-conception age and birth weight. In the first step of each regression birth weight and post-conception age at MRI were entered stepwise (Model 1). In the second step (Model 2) the SES Composite was added to the regression. To assess independent contributions of maternal education and ITN, models were run separately for each of these variables. As the correlation between these two variables was high ($r=0.86$, $p<0.001$) entering them together in the model would limit our ability to test for individual effects of these SES indicators (Noble, et al., 2012). These individual models are referred to as Model 3 (ITN) and Model 4 (maternal education).

For cortical gray matter, in Model 1, birth weight, but not age at MRI, was retained in the model ($R^2=0.38, F(1,42)=25.17, p<0.001$). Addition of SES Composite in Model 2 resulted in significant increase in amount of variance accounted for by the model ($\Delta R^2=0.082, F(1,41)=6.21, p=0.017$). In Model 3 and Model 4, respectively, both ITN ($\Delta R^2=0.10, F(1,41)=18.69, p<0.001$) and maternal education ($\Delta R^2=0.10, F(1,41)=18.65, p<0.001$) predicted cortical gray matter volumes. In the regression on deep gray matter volume birth weight but not age at MRI was retained in Model 1 ($R^2=0.22, F(1,42)=1.87, p=0.001$). Adding SES improved the model significantly ($\Delta R^2=0.073, F(1,41)=4.22, p=0.046$). The addition of ITN alone in Model 3 had a borderline effect on model fit ($\Delta R^2=0.061, F(1,41)=8.03, p<0.069$), and addition of maternal education alone in Model 4 did improve the model for deep gray matter volume

by the 0.05 criterion (ΔR^2=0.076, F(1,41)=8.64,p=0.041). In the regression for white matter volume, birth weight and age at MRI were retained after the stepwise entry in Model 1, (R^2=0.32,F(1,41)=9.85, p<0.001). Addition of SES in Model 2 did not significantly improve the model (ΔR^2=0.015,F(1,40)=6.85,p=0.35) and addition of ITN (Model 3) and maternal education (Model 4) showed no improvement to the model for white matter volume (p≥0.51). Table 3 shows regression statistics for the 4 models for each outcome. Figure 1 illustrates the positive relationships between SES and cortical gray and deep gray matter volumes adjusted for variables retained in the final models.

Discussion

In this cohort of healthy term infants, MRI showed SES-dependent differences in gray matter volume at the young age of 5 weeks. Both cortical gray matter, which includes the cortex of the two hemispheres and hippocampi, and deep gray matter, which includes the thalamus and basal ganglia, were significantly smaller in low SES infants. No difference was observed in white matter volume. Low SES is associated with lower birth weights and increased risk for prematurity, both of which are closely linked to brain development (Aber, Bennett, Conley, & Li, 1997; Osofsky, 1974; Parker, Greer, & Zuckerman, 1988). The present results from a cohort of healthy term infants show SES effects on brain development, independent of post-conception age and birth weight.

Data initially were analyzed utilizing the SES Composite of two well-established factors associated with SES, ITN and maternal education, with results showing a significant association between SES and cortical and deep gray matter volume. We then examined the effects of these two factors on brain volumes individually. Due to their co-linearity, which has been shown to confound interpretation of results when included

together (Lawson, et al., 2013; Noble, et al., 2012) these were entered separately in models 3 and 4. For cortical gray matter the ITN and maternal education coefficients and significance levels were comparable each other and to that for the SES composite. For the analyses of deep gray matter, coefficients were similar and significance levels for these two factors were close to the 0.05 threshold. Hanson et al, report a similar association between lower SES, indicated by household income, and lower total gray matter volume (Hanson, et al., 2013), with no analysis of the influence of maternal education. Lawson et al (2014) found an association between cortical thickness in frontal regions of interest and maternal and paternal education but not family income. While findings are mixed in regard to which factors are associated with neural outcomes, taken together, they show a consistent effect of SES. The differences in relationships reported in the literature may reflect differences in the range of SES examined, or the multiplicity of factors (social support, nutrition, stress) that influence outcomes and their variance across SES.

The results reported here add to a growing literature on SES and brain development and push back the age at which brain correlates of SES can be observed from early childhood to early infancy. Two studies have reported functional brain activity differences within the first year of life: Tomalski et al. (2013) reported EEG differences between low and middle SES infants between 6 and 9 months of age; and Gao et al. (2014) reported marginal effects of SES on fMRI resting functional connectivity at 6 months of age (Gao et al., 2014; Tomalski et al., 2013). The present results show that SES effects are manifest in the brain at an even earlier age. In addition, because structural findings are not dependent on arousal, distress, sleep deprivation or

other states that affect functional measures, the present results point more decisively to trait-like differences in brain development.

We hypothesized that SES related differences in brain volume might be observable as early as one month. For this study we enrolled mothers at time of delivery, and only those meeting strict criteria for being non-high-risk. The question of what causes the differences observed here cannot be answered on the basis of the available data. Possible etiologies include differences in post-natal environment, differences in prenatal environment, and differences in genes (Boyce & Kobor, 2015; Cordero, 1990; Hackman, Farah, & Meaney, 2010). Post-natal influences could include the effects of nutrition, sleep quality or stress among countless other factors (Buss et al., 2007). The prenatal environment influences brain development by these and other factors, including maternal health and toxin exposure, which are known to vary by SES (Dipietro, 2012; Hackman, et al., 2010). Genetic factors cannot be excluded. While such influences are shown in behavioral outcomes at later ages, especially in higher SES samples (Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003), the influence of genes on the relation between SES and neural outcomes has not yet been explored.

Limitations of this study are several. First, our eligibility requirements, chosen to increase power by eliminating the need to control for influential confounders such as gender and race/ethnicity, impose a predictable limitation on generalizability. Regardless, findings inform for an understudied minority, and provide a template for exploration of neural outcome at very young ages in other cohorts. Second, sample size may be considered a limitation; however, a final n of 44 infants scanned at one month of age without sedation in a study evaluating effect of SES disparity is, to our knowledge

unique. Finally, given that our data suggest prenatal effects of SES on gray and deep gray matter volumes, we do not have a robust prenatal database that would allow for a careful evaluation of prenatal influences.

Our ongoing longitudinal follow-up will determine whether SES effects on neural outcomes detected at 1 month are increased or decreased at 12 months, and whether there are relationships between volumetric findings and infant cognitive outcomes. Future studies will utilize a prenatal enrollment strategy rather than enrollment at delivery, allowing for assessment of maternal nutrition, stressors, and other lifestyle factors during pregnancy. As many neurodevelopmental disorders stem from atypical brain development over the first few years of life (Kolb, Mychasiuk, & Gibb, 2013), our findings heighten concern for increased risk of early developmental compromise in low SES children. On the other hand, it also is well established that early intervention and enriched environments can ameliorate compromised developmental outcomes (Blair & Diamond, 2008; Brooks-Gunn, Klebanov, Liaw, & Spiker, 1993; Campbell, Pungello, Miller-Johnson, Burchinal, & Ramey, 2001; Reynolds, Temple, Robertson, & Mann, 2001; Rose, Herzig, & Hussey-Gardner, 2014; Shonkoff et al., 2012). Current efforts directed toward reduction of risks posed by SES disparity are focused on the preschool years, possibly well after early foundational neural growth (Spann, Bansal, Rosen, & Peterson, 2014); we suggest increased focus during infancy.

Our study, for which the long term goal is examination of effects of SES disparity on neural and developmental outcome, joins a growing number of investigations examining brain structure and outcome of infants and young children. The relation between neural status at 1 month of age and subsequent cognitive outcome was reported

by Spann et al (Spann, et al., 2014) in 33 infants; correlations between cerebral surface morphology and subsequent motor, language, and cognitive scores were reported. Can et al (Can, Richards, & Kuhl, 2013) in 19 infants, scanned at 7 months and evaluated at 12 months, found relations between early gray-matter and white-matter concentration and language skills. Amygdala volume was found related to language outcome in infants scanned at 6 months and evaluated as early as two years (Ortiz-Mantilla, Choe, Flax, Grant, & Benasich, 2010), with another investigation showing an association of white matter microstructure and infant working memory in infants imaged at 12 months (Short et al., 2013). These researchers, however, did not examine SES effects in their cohorts.

What do the present results imply for our understanding of child development in poverty, and for child policy? Early differences in brain structure have been linked to later cognitive development (Can, et al., 2013; Ortiz-Mantilla, et al., 2010; Short, et al., 2013; Spann, et al., 2014). These links across development suggests that differences in neural structure may be early indicators of increased risk for disadvantage in academic readiness faced by poor children. Whatever their cause, the existence of such differences so early in life suggests that intervention cannot start too early in supporting young families. Some highly effective early intervention programs are initiated in the first months of life with some providing prenatal as well as post natal visits, parenting classes, nutritional, and other forms of support (Austin, Lemon, & Leer, 2005; Raikes et al., 2006; Tamis-LeMonda, Bornstein, & Baumwell, 2001).

Conclusions

In this cohort of term healthy females, lower SES was associated with smaller cortical gray and deep gray matter volumes at age 1 month. Future studies designed to more fully parse the relative contribution of the prenatal environment and individual covariates of SES are needed. Because at this early age, brain development is characterized by rapid synaptic growth and neural plasticity, findings reported here underscore the need to monitor and optimize development of our youngest through programs and policies directed at reducing impact of SES disparities (Heckman & Mastrov, 2007; Knudsen, Heckman, Cameron, & Shonkoff, 2006; Shonkoff, et al., 2012).

Table 1. Infant Characteristics at Time of Enrollment and MRI by SES group

	Low SES Group n=25	Higher SES Group n=19	p-value
Enrollment Characteristics			
Mother's Age, yr	24.1 ± 4.9[a]	27.1 ± 5.6	<0.001
ITN			
Below Poverty Line	25 (100%)	0	
Above the Poverty Line	0	19 (100%)	
Mother's Education			
1. Less than High School	16 (64%) [b]	0	
2. High School/GED	6 (24%)	3 (16%)	
3. Technical/Vocational	3 (12%)	1 (5%)	
4. Some College	0	5 (26%)	
5. Two-year Degree	0	5 (26%)	<0.001
6. Four-year College Degree	0	4 (21%)	
7. Some graduate school	0	0	
8. MA, PhD, Professional	0	1 (5%)	
Gestational Age, weeks	39.4 ± 1.0	39.6 ± 0.9	0.35
Birth Weight, kg	3.29 ± 0.44	3.42 ± 0.44	0.36
Birth HC[c], cm	33.5 ± 1.3	34.0 ± 1.4	0.33
Birth Length, cm	50.2 ± 2.3	50.3 ± 2.3	0.91
1-Month Characteristics			
Age at MRI			
Post-conception, wks	44.7 ± 0.5	45.0 ± 0.9	0.17
Post-natal, wks	5.0 ± 0.9	5.0 ± 1.2	0.90

[a] mean±sd, [b] n (%) ; [c] Head Circumference

Table 2. Correlations between Cortical Volumes and Participant Characteristics

	Cortical Gray Matter	Deep Gray Matter	White Matter
SES Composite	0.38(0.01)[a]	0.34(0.024)	0.25(0.096)
Income-to-Needs	0.37(0.014)	0.28(0.063)	0.11(0.48)
Maternal Education	0.41(0.006)	0.34(0.022)	0.22(0.15)
Paternal Education	0.13(0.40)	0.27(0.076)	0.22(0.15)
Gestational Age	0.30(0.046)	0.19(0.214)	0.18(0.23)
Birth Weight	0.64(0.000)	0.47(0.001)	0.53(0.000)
Head Circumference	0.64(0.000)	0.46(0.002)	0.45(0.003)
Birth Length	0.30(0.050)	0.31(0.047)	0.16(0.32)
Age at MRI			
Post-conception, wks	0.49(0.001)	0.40(0.007)	0.48(0.001)
Post-natal, wks	0.078(0.61)	0.068(0.66)	0.12(0.46)

[a] Pearson r (p-value), n=44

Table 3. Hierarchical Linear Regression Analyses predicting Cortical Gray Matter, Deep Gray Matter and White Matter Volumes

	Cortical Gray Matter	Deep Gray Matter	White Matter
Model 1			
Age at MRI	—	—	0.30 (0.044)
Birth weight	0.61 (.000)*	0.61 (0.000)	0.36 (0.019)
R^2	0.38	0.22	0.32
F (df)	25.17 (1,42)	11.87 (1,42)	9.85 (1,41)
p-value	<0.001	0.001	<0.001
Model 2			
Age at MRI	—	—	0.27 (0.077)
Birth weight	0.57 (0.000)	0.43 (0.003)	0.35 (0.021)
SES Composite	0.29 (0.017)	0.27 (0.046)	0.13 (0.35)
R^2	0.46	0.29	0.34
ΔR^2	0.082	0.073	0.015
F (*df*)	6.21 (1,41)	4.22 (1,41)	6.85(1,40)
p-value	0.017	0.046	0.35
Model 3			
Age at MRI	—	—	0.30 (0.047)
Birth weight	0.59 (0.000)	0.45 (0.002)	0.35 (0.022)
ITN	0.32 (0.007)	0.25 (0.069)	0.066 (0.61)
R^2	0.48	0.28	0.33
ΔR^2	0.10	0.061	0.004
F (*df*)	18.69(1,41)	8.028 (1,41)	(1,40)
p-value	<0.001	0.069	0.61
Model 4			
Age at MRI	—	—	0.28 (0.072)
Birth weight	0.56 (0.000)	0.43 (0.003)	0.36 (0.020)
Maternal Ed	0.32 (0.007)	0.28 (0.041)	0.089 (0.51)
R^2	0.48	0.30	0.33
ΔR^2	0.10	0.076	0.007
F (*df*)	18.65 (1,41)	8.64(1,41)	(1,40)
p-value	<0.001	0.041	0.51

*Standardized regression coefficient (p-values, 2-tailed)
Model 2 Predictor: SES Composite
Model 3 Predictor: ITN
Model 4 Predictor: Maternal Education

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